National Bureau of Standards

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DETROIT

Electron-Optical Mapping of the Space-Charge Field in a Magnetron

An accurate, sensitive technique [1] for experimentally determining the electric-field distribution and space-charge density within a magnetron has been developed by D. L. Reverdin at this bureau. The new method, which is also well suited to investigations of electron-optical lenses, gas discharge, and other space-charge problems, is a modification of the electron-optical shadow technique [2] recently developed at the Bureau for the quantitative study of minute electric and magnetic fields. A magnetic lens is used to produce shadow images of two fine wire screens placed at either end of the magnetron in the path of an electron beam. Then, from the distortion in the shadow network caused by deflection of the electron rays as they pass through the magnetron field, the radial electric field is computed. These results are used to obtain the space-charge distribution.

The magnetron is a vacuum tube widely used for generating power at microwave frequencies. In its elementary form, it consists of a cylindrical cathode—ordinarily a straight-wire filament—and a coaxial cylindrical anode. The tube functions under the joint action of an externally applied magnetic field and the electric field created by applying a direct-current potential between the anode and cathode.

The high space-charge density within a magnetron is known to have an important bearing on performance. However, very little is actually known concerning the electric-field distribution and space-charge configuration within the tube. Although the problem has been investigated theoretically [3] by many workers, the formidable mathematics involved has not permitted an exact solution, and the various simplifications of the theory that have been suggested have led to widely divergent results. Attempts at direct measurement have also proved unsuccessful, because the very critical symmetry of the field under study was disturbed. A promising approach to the problem has now been provided by the method developed at the Bureau. This technique has been used to map the charge distribution within a cut-off or steady-state magnetron. Further application to oscillating magnetrons should lead to a much better understanding of their operation and should yield information of considerable value to the engineer who is interested in designing improved types of magnetrons or in predicting the performance of existing types.

The Bureau's method uses an electron beam as a probe but keeps the charge density of the probe beam small compared to the space charge in the magnetron. Thus, the field under study is undisturbed. An electron gun sends the beam axially through the tube.

[1] This work was carried out in connection with a doctoral dissertation submitted by D. L. Reverdin to George Washington University, Washington, D. C., in February 1950. Dr. Reverdin, formerly a guest worker at the National Bureau of Standards, has now returned to Switzerland.

[2] For further technical details, see Electron-optical shadow method, NBS Technical News Bulletin **33**, 106 (Sept. 1949).

[3] A. W. Hull, Phys. Rev. **18**, 31 (1921); L. Brillouin, Phys. Rev. **60**, 385 (1941).

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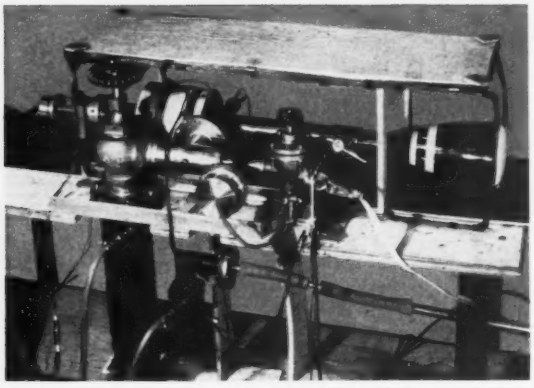
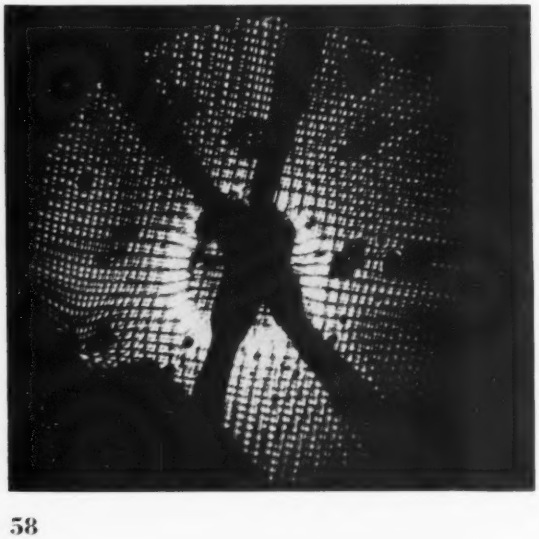


The Bureau's electron-optical shadow technique has been adapted to measure the electric-field distribution and space-charge density within the magnetron, by means of a specially designed cathode-ray tube. The magnetron is placed in the long horizontal tube in the path of a beam of electrons produced by an electron gun (left).

Coaxial coils surrounding the magnetron provide a homogeneous magnetic field for the operation of the magnetron and at the same time act upon the beam as a convergent magnetic lens, bringing it to a focus beyond the tube. Two fine wire screens are placed in the path of the electrons, one just in front of the magnetron, the other just beyond the back focus of the beam. A complex shadow pattern due to the two wire screens is then formed on a fluorescent screen. When the direct-current potential across the magnetron is zero, the pattern is undistorted. However, when an electric field is applied to the magnetron, the shadow network on the fluorescent screen becomes quite distorted; and theoretical analysis of this effect has related the distortion of a given part of the pattern to the intensity

In a typical shadow pattern distorted by the magnetron field, a space-charge ring is clearly visible (light area, center); the lack of sharpness in this region provides a visual indication of the tube noise within the magnetron.



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U. S. Department of Commerce

Charles Sawyer, *Secretary*

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E. U. Condon, *Director*

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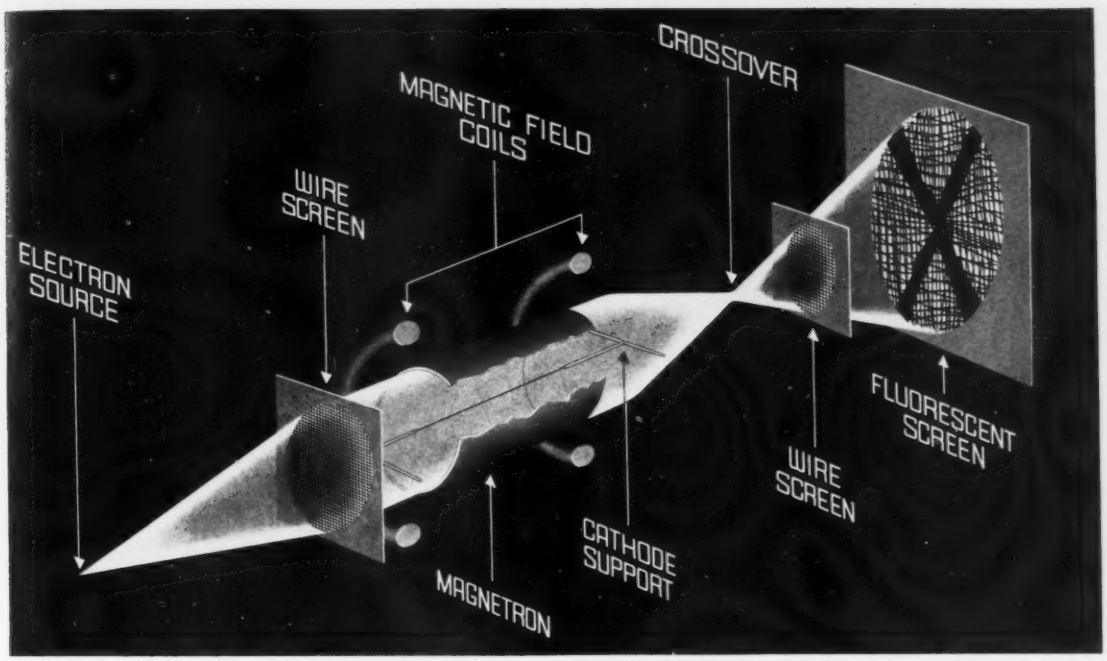
of the electric and space-charge fields in the corresponding region of the magnetron.

In practice, photographs are taken of the shadow network, both in the undistorted and distorted form. The changes in the paths of the electron rays as they pass through the magnetron are then determined from measurements of the shadow patterns and the geometrical constants of the system, such as the positions of both wire screens, the magnetron, and the electron source, and the number of meshes per unit length of the wire screens used. From the deflection of an electron ray entering the magnetron at a given radial distance from the center, the strength of the electric field in the corresponding region of the magnetron is computed.

In comparison with previous methods using a pencil beam of electrons but no optical system, this method is much more sensitive and accurate. It also has the advantage of giving a complete field map in a very short time. The principal source of error lies in the uncertainty regarding the configuration of the electric fringe field at either end of the magnetron under space-charge conditions.

The Bureau's study of the field within a steady-state magnetron indicates that the actual space-charge distribution differs considerably from that predicted by the theorists. A number of different shapes of space-



The beam of electrons from an electron gun serves as a probe for mapping the magnetron field. A magnetic electron lens, the field of which is produced by two coaxial coils surrounding the magnetron, is used to form shadow images (on the fluorescent screen) of two fine wire screens placed in the path of the beam. The same magnetic field serves for operation of the magnetron. Deflection of the electron rays by the magnetron causes distortion in the shadow network, which may be measured, and from which the electric-field and space-charge distribution are computed.

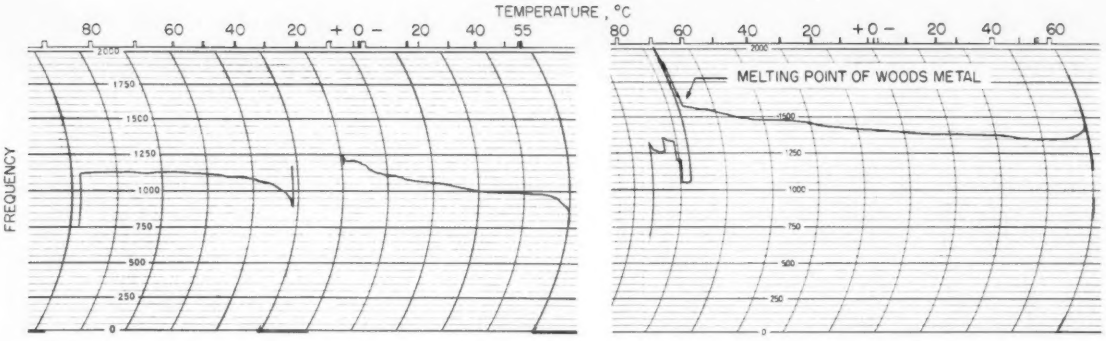
charge configuration were observed that are closely related to the symmetry of the magnetron. A certain lack of sharpness noted in the patterns gave a visual indication of the noise in the tube. This suggests further extension of the method to learn more about the problem of noise in an oscillating magnetron.

Loading Quartz Crystals to Improve Performance

The erratic performance of piezoelectric plates has long been a problem in the production of oscillator units, and many investigations have been undertaken to determine the causes of instability. Experimental results obtained by Leland T. Sogn of the Bureau's constitution and microstructure laboratory over the past few years show that it is possible to improve the performance of certain types of thickness-shear quartz plates by coating their surfaces with some inert material. Two distinct effects have been noted: First, that produced by an amount of the loading material so small that the resultant frequency change is as little as 0.03 percent of the crystal fundamental; and, second, that produced by a much larger mass of the loading material properly distributed over the central area of the crystal. The latter seems to have the beneficial effects now achieved by contouring, a difficult and expensive process. The potential usefulness of loading thin crystals to improve performance as well as to recover plates ground too thin in the production stage should encourage further research on the various aspects of quartz-crystal loading.

A phenomenon associated with a wedge-shaped 0.5- by 0.6-inch BT oscillator plate (width parallel to the X-axis) prompted the present investigations. When the electrodes coupling the oscillator plate to the electronic circuit were placed over the thicker portion of the plate, the frequency was not only lower, as anticipated, because frequency is inversely proportional to thickness, but the activity was considerably higher, shown by the magnitude of the grid current. Lower frequency was associated with higher activity or amplitude of vibration, and vice versa.

To investigate this phenomenon, a small $\frac{1}{4}$-inch probe electrode was employed. With this electrode, it was possible to confine the energy fed back from the electronic circuit to a small area of the plate and thereby obtain a series of frequencies and activities as the electrode was moved in short steps from the thick to the thin portion of the plate. In "flat" plates the frequency fluctuated about a mean value as the electrode was moved over the plate surface, and it was found that activity measurements as well as frequency measurements can be used to detect minute differences



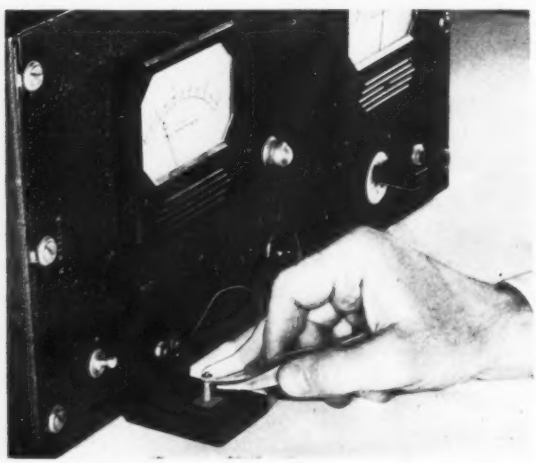
The improved performance that results from "loading" thickness-shear quartz plates is revealed by comparing the frequency curves for an AT crystal, unloaded (left) and loaded with woods metal (right). The dip near 78° C in the loaded-crystal curve is due to melting of the metal. Activity curves for the same crystal on the next page.

in thickness that are not disclosed even by instruments sensitive to differences of less than 20 microinches. Activity readings were actually used to check and control the contour of plates during the process of hand-grinding.

In most of the hand-finished plates used in these experiments, positions determining a certain frequency were found to be scattered indiscriminately over the surface, although some oscillator plates had contour and edge conditions such that only a few, nearly equal frequencies could be obtained. For example, in an 8.7-Mc plate with only two frequencies about 5 kc apart, the frequencies would alternate from one to the other as the electrode was moved across a line roughly parallel to the *X*-axis, which divided the plate into two approximately equal areas. This plate apparently was composed of two approximately equal flat areas that differed in thickness by the equivalent of a 5-kc difference in frequency. The balance between the two frequencies was so delicate that a rapid alternation between the two frequencies could be obtained by adjusting the temperature or circuit constants, resulting in an audible "motorboating" effect in the measuring equipment. Changing the length, or *Z* dimension, by alternately grinding opposite edges (parallel to the *X*-axis) produced anticipated results. When the edge bounding the thick end of the plate was ground, the higher frequency became dominant because the area of the thin, high-frequency plateau became relatively larger. Subsequent grinding on the other edge reversed the effect: when the thicker area was relatively larger, its lower frequency was dominant. This procedure was repeated several times with identical results.

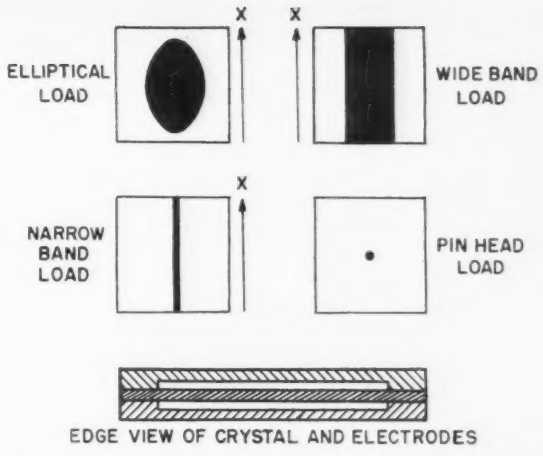
Experiments were also carried out using machine-lapped convex crystals. Results were similar, but one new fact was disclosed. The lowest frequency, excited when the small electrode was placed at the exact center of the plate, did not give greatest activity. Instead the optimum activity, 50 percent higher, was obtained by moving the electrode to a different position near the center. Shifting to the thinner edges was accompanied by increasing frequency and decreasing activity; moving from the optimum point toward the center caused both activity and frequency to decrease. The area of the crystal and the frequency range over which this anomalous behavior occurred were small. For example, in a 10-Mc plate that had an edge-to-center frequency variation of 25 kc, the frequency that gave maximum activity was about 5 kc higher than the lowest frequency that could be obtained; the electrode position in this case was about one-fifth the distance from the center to the corner of the plate. Typical activity values, as indicated by the rectified grid current from the oscillator tube, were 0.5 at the center of the plate, 0.8 at the optimum position on the plate, and 0.2 at the corner.

Temperature runs (−60° to +90° C) were made on several ½-inch-square 10-Mc plates that had centers about 0.00005-inch concave. All had activities that varied constantly between 0 and 0.2 milliampere over the temperature range, and frequencies that were correspondingly unstable. These oscillator blanks were etched slightly to raise their frequencies 3 to 5 kc and



A small ¼-inch probe (lower left) is used to observe changes in activity and frequency as it is moved over the surface of quartz-crystal oscillator plates. Fluctuations in these quantities reveal minute differences in thickness between different portions of the plate.

Several different "load-patterns" were applied to oscillator plates. Most effective were the elliptical and the wide-band patterns when applied in the direction of the X-axis. The lower portion of the diagram is an enlarged cross section of a crystal mounted between electrodes.

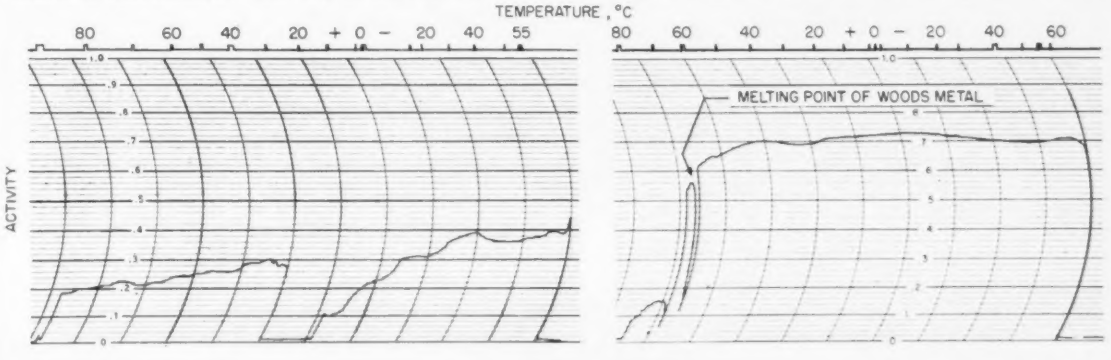


then were loaded to their original frequency, thereby reestablishing the original relationship between the fundamental and other secondary modes. The loading material was woods metal, applied lightly in a ¼-inch diameter circle concentric with the center of the plate. The effect was a more than threefold increase in the activity (0.2 to 0.7 milliamperes or more). Subsequent temperature runs revealed that the increased activity was associated with a general improvement in operating characteristics over the entire temperature range. Also, the resistance at series resonance, R_s, decreased several fold, while the Q increased correspondingly. Since the same frequency-dimension relationships were maintained, factors other than the usually ascribed coupling phenomena are responsible in some measure for the erratic behavior: perhaps the most important of these is the frequency at which the plate is being driven. In general, it appears that plates whose central active areas have a frequency that is too high for the plate as a whole tend to have poor frequency stability and activity. Elimination of this condition can very easily be effected through a lowering of the frequency by placing a small mass of material upon the central areas.

Loading certain areas of lower-frequency plates very heavily has also been found to be beneficial. It has long been known that giving a slight convexity to some types of oscillator plates results in improved performance. Recent experiments indicate that if this contouring takes the form of a plateau at the center with tapering edges, the performance is improved even more. It appears that heavily loading the central portion of the plate produces effects very similar to those produced by the plateau with tapering edges. It is believed that in both cases the thickness-shear vibration is mainly confined to the central area because the surrounding area is so far off frequency that it remains relatively inert. A difficulty commonly found in mounting low-frequency plates is their failure to oscillate when pressure is applied to the corners—e. g., when a plate is pressure-mounted between electrodes with raised areas at the corners. Although the active portion of very thin plates in thickness-shear is mostly restricted to the central area, the flexural vibrations that may also be present become quite active at lower frequencies (thicker plates). This may be corrected either by contouring or by properly loading the plates, which may then be securely clamped at the corners with no great reduction in activity.

Several loading materials, both metallic and nonmetallic, have been used effectively. Woods metal has certain advantages in hand application because it is soft, adheres well to the quartz, and can easily be removed. The amount of metal for satisfactory results varies with the percentage of the area coated as well as with the shape of the coated area. An elliptical pattern with the long axis parallel to the X-axis has good effect, and a band across the plate in the X-axis direction, covering about one-third the area of the plate, is also effective. A narrower band parallel to the X-axis is less effective, whereas similar patterns rotated 90° (long dimensions perpendicular to the X-axis) are still less effective; a narrow band perpen-

Activity curves for an AT crystal oscillator plate, unloaded (left) and loaded with woods metal (right), also reveal improved performance. The dip in the curve for the loaded crystal near 78° C indicates melting of the metal.



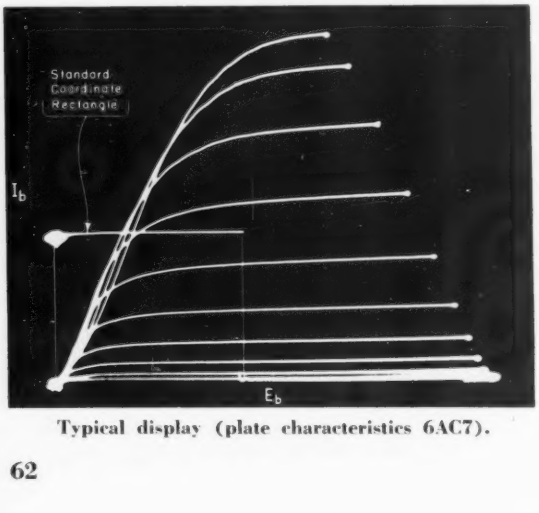
dicular to the X-axis appears to have a deleterious effect. In most of the experiments, an equal amount of woods metal was applied to both faces of a plate. (When the coated area is the size of a pinhead, an interesting effect occurs: The frequency decreases at first, as expected, but further application of metal causes the frequency to jump to a point many kilocycles higher than the original frequency.)

Curve Generator For Electron Tubes

An instrument that gives an instantaneous visual display of electron tube characteristics has been developed by Milton L. Kuder at this Bureau. The curve generator plots directly on the screen of a cathode-ray oscilloscope the family of plate current versus plate voltage curves for any receiving tube. A standard rectangle is displayed along with the characteristic curves to provide a direct scale for voltage and current readings. In cases where the tube characteristics are not known or where an unusual combination of supply voltages is to be used, the curve generator can provide tube data at a great saving in time and labor.

The plate voltage applied to the tube under test is swept continuously from zero to predetermined positive values. The voltage drop appearing across the plate load resistance is then a measure of the plate current. This voltage drop is applied to the vertical deflecting plates of a cathode-ray oscilloscope and the plate voltage itself to the horizontal plates. The combined voltage generate a plate-current–plate-voltage curve on the oscilloscope screen for the entire sweep interval. The sweep sequence is repeated automatically for several values of grid bias, forming the family of plate characteristic curves. A series of bright dots appearing at the end of each curve in the family gives a useful representation of the load line of the tube for the operating conditions selected.

In addition to producing plate characteristic curves, the new instrument can provide a visual representation of plate current versus grid voltage. In this case the oscilloscope display is particularly convenient since grid voltage increments are directly defined by calibrated vertical bars appearing on the oscilloscope screen; a standard current reference is given by a horizontal bar. All of the possible displays are produced by the curve generator without overloading the tube under test. Over-all accuracy of voltage and current readings from the oscilloscope screen is within plus or minus 5 percent.



Typical display (plate characteristics 6AC7).

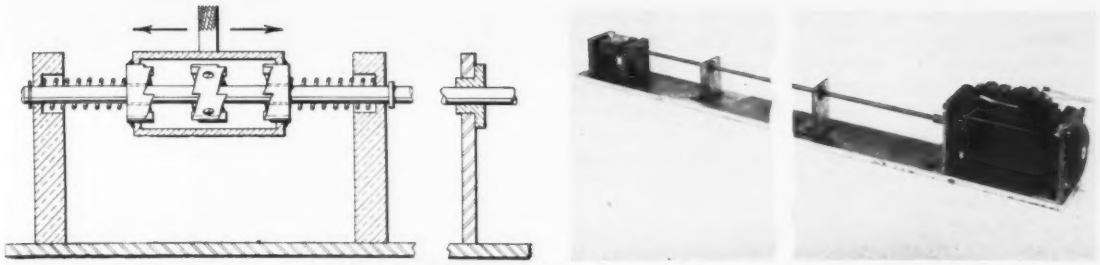
A complete family of curves is retraced 60 times a second; the resulting image is stationary and free from flicker. Characteristic curves may be quickly obtained in permanent form by photographing the screen image with a regular oscillograph camera. Electronic research and development organizations would find this procedure extremely valuable on many occasions.

All of the driving signals are produced in the generator by a single master oscillator. Voltage excursions for the tube under test are obtained from the oscillator in the form of a rising sawtooth wave whose magnitude is controlled without any oscillator loading effect. A cathode follower isolates the power supply for the tube under test from the rest of the generator circuit, so that only the plate current of the tested tube is plotted on the oscilloscope.

When the sawtooth-plate sweep signal is most negative, the master oscillator sends a pulse into a pulse former. Pulses from the pulse former then operate a step counter to provide a fixed-bias voltage for the grid of the tube under test, successively becoming more positive. Each time the plate voltage is driven negative, the grid-bias voltage rises to a new level. These stepwise-increasing bias voltages are fed through a video divider that reduces their amplitude to the desired level. From the divider they go through a cathode follower to the test grid. A special control acting on a clipper circuit allows manual selection of a calibrated voltage for the highest positive grid step.

A special linearizing circuit provides for uniform increments in the step sequence of grid voltages, each oscillator pulse, through an inverse feedback arrangement, transferring a fixed charge into a large capacitor. The feedback can be controlled manually to provide any size grid-voltage increment. The number of steps is controlled indirectly by the output of a step counter, arresting the entire process after a predetermined number of steps.

Two circuits have been included in the design of the characteristic curve generator that are not vitally necessary, but which add to the convenience and reliability of the instrument. One is a "servo-sweep" circuit whose timing is controlled through the frame synchronizing switch. This circuit is especially useful for viewing the step-function signal at the grid of the tube under test. Another circuit, using four tubes, identifies the curves that have positive values of grid bias by means of a small marking "pip" superimposed on the positive grid lines. The curve generator, essentially as described, will soon be available commercially.



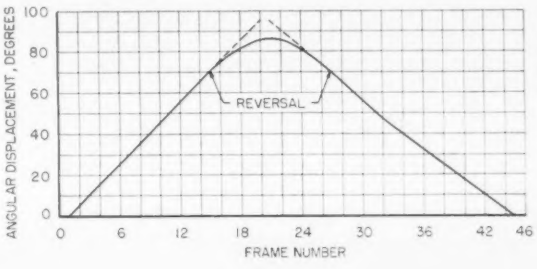
The apparatus for rapid reversal of electric motors includes a torsion bar and two unidirectional clutches (details, left). The torsion bar, connected rigidly to the motor shaft, acts as a reversal spring. The clutches are attached to the other end of the bar. When the proper clutch is engaged, rotation of the bar is stopped; this also stops the rotor. Energy stored in the torsion bar by the sudden stop is then returned to the rotor, thus reversing the motor.

High-Speed Reversal of Electric Motors

A method for reversing a small electric motor in 3 to 4 milliseconds has been developed by Jacob Rabinow at this Bureau. Designed specifically to meet the need for high-speed reversal of magnetic tapes in the memories of electronic digital computing machines, the technique may prove useful in many other applications.

Although it is relatively easy to stop a motor quickly by the use of brakes, rapid starts in either the same or the reverse direction are limited by the low torques that can be obtained by electromagnetic means alone. In the Bureau's rapid-reversal motor, the kinetic energy of the rotor, instead of being dissipated as heat in a brake during deceleration, is converted into potential energy in a spring, which is then used to accelerate the rotor rapidly in the opposite direction.

A small low-inertia two-phase motor operating at 3,200 rpm was used. The reversal spring consists of a steel torsion bar approximately 31 inches long and $\frac{3}{16}$ inch in diameter. Only one phase of the motor is connected to the alternating-current power supply; thus the motor will rotate in the starting direction, either clockwise or counterclockwise. The motor shaft is rigidly connected to one end of the torsion bar, which is equipped at the other end with two positive unidirectional clutches. One clutch prevents clockwise, and the other counterclockwise, rotation. If the motor is rotating in a clockwise direction and the proper clutch is engaged, the adjacent end of the torsion bar is thereby stopped; this brings the rotor to a stop in approximately 20 degrees. The potential energy stored in the torsion bar is then returned to the rotor in the form of a counterclockwise impulse. The motor attains virtually full speed in the new direction within about 2 milliseconds.



The curve obtained when angular displacement of the rotor is plotted against frame number of the film indicates that the motor was reversed in about 12 frames or 3 milliseconds.

Two methods were used in the Bureau's investigation to check the reversing time of the motor. For the simpler test, a black disk provided with a white index-line was mounted on one end of the motor shaft and photographed against a circular scale, using a high-speed motion-picture camera at approximately 4,000 frames per second. When the film is run through a projector at the normal rate of 16 frames per second, the behavior of the disk is easily observed.

A second means of measuring reversal speed, suggested by Frank Shepard of the Shepard Laboratories, involves locking the far end of the shaft and applying direct current to one winding of the motor, while alternating current is supplied to the other winding. Oscillations are thus induced in the rotor-torsion bar. Varying the frequency of the current makes it possible to determine the frequency of torsional resonance. The time required for the rotor to reverse can be easily computed, since it is one-half of one period of a torsional oscillation at resonance. The resonance in the system tested occurred at approximately 125 cycles per second, indicating (in a period of 8 milliseconds) a reversal time of 4 milliseconds.

In the experimental model of the rapid-reversal mechanism built at the Bureau, the clutches are operated manually, but it is expected that in normal use the clutch mechanism will be operated by suitable electromagnetic controls. Although the studies thus far have used a small motor of about 1/75 hp, it is anticipated that motors of all sizes could be reversed rapidly by this technique, the speed of reversal being limited only by the mechanical strength of the various parts.

It would be entirely feasible to utilize other types of energy-storing devices, such as coil springs or pneumatic cylinders, instead of the torsion shaft. It would also be possible to use a stationary energy-storing system and to locate the reversing clutches between it and the motor shaft.

The choice and use of materials for operative and restorative dentistry present many difficulties. Small cavities with fixed, unyielding walls must be restored with materials that are harmless to the mouth and yet have the physical and chemical properties necessary to withstand the forces of mastication and the action of the oral fluids. Dentures must fit accurately, must neither expand nor shrink, and must also withstand relatively large forces. The problem is further complicated by the great variety of materials needed and the many different brands of each type offered for sale. For example, there are now on the market several hundred dental-gold alloys for making inlays, more than 65 different alloys for making amalgam restorations, and 50 brands of resins for constructing partial or full dentures.

Of the $364,000,000 spent for dentistry by this country in 1948, over $100,000,000 was for dental material. Yet for many years the only information available to the practicing dentist on the properties of these products came from the limited amount of research, mostly clinical, that was done in a few dental schools and from the research that could be financed by manufacturers of dental products. This information was very often incomplete, conflicting, and in many instances completely erroneous.

To meet the need of the dental profession, the National Bureau of Standards therefore established a broad program of research on dental materials that, over the past 30 years, has aided materially in the solution of many of the problems encountered in dentistry. This program has included investigations of the fundamental physical, chemical, and engineering properties of dental products, the development of special equipment and methods for evaluating these properties, and the clinical application of the findings. In addition, specifications for dental materials are developed, and dental materials are tested and certified for conformance to specifications. An educational program is also conducted to disseminate the results of the work in such a way as to encourage their early acceptance and use by the dental profession and industry.

The work at the National Bureau of Standards on dental materials originated in 1919 in response to a request from the War Department for assistance in the evaluation of dental products purchased by the various Federal dental services. Nine years later the Research Council of the American Dental Association established a cooperative research program with the Bureau. Since that time the efforts of the staff of chemists, physicists, and dentists maintained at the Bureau by the ADA have contributed greatly to the success of the program, and the Dental Association's participation has developed into one of the major research activities of the Association.

In view of the widespread acceptance of the results of the work by the dental profession in this country and abroad and the apparent need for continued research on a more extensive scale, the Bureau's program on dental materials was further expanded in 1947. Experience gained in the earlier work had indicated a need for a closer correlation of clinical behavior with the data obtained in the laboratory. A complete dental operative unit was therefore added, and clinical investigations of the more commonly used restorative materials were undertaken. Through the cooperation of the members of the Bureau staff, experimental dental restorations are now placed in the mouth under controlled conditions. The behavior of these restorations in service is then carefully observed and correlated with the data obtained in the laboratory experiments. The increased facilities also greatly accelerated the investigation of new products that are constantly being offered to the dental profession, often without adequate data to substantiate the claims made for them or without sufficient information for their proper use.

During the recent war, the dentists of the Armed Forces experienced difficulties in the use of dental products under conditions not usually encountered in civilian practice. In tropical areas, for example, it was often impossible to place silicate-cement fillings, alginate impression materials deteriorated badly, and many of the synthetic-resin denture materials polymerized in transit or in storage. These failures were costly in equipment and shipping and storing space. In order to eliminate such difficulties as far as possible, a

(A) The temperature rise during the hardening of a denture Bureau's dental research laboratory. (B) Experimental s are on materials and techniques. (C) Clinical observation of restora inated dental amalgam shown by fracture of glass tubing. Casting ometer detects tendencies toward shrink ntal a

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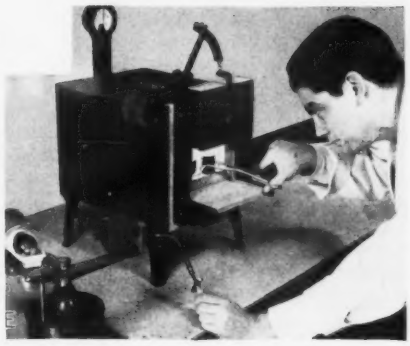
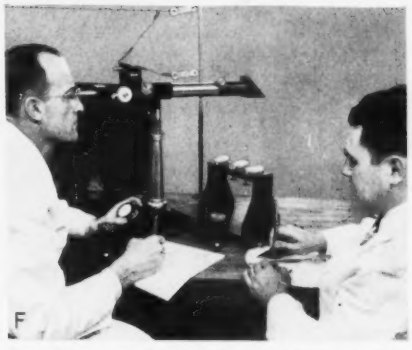




f a dental restoration is measured under actual clinical conditions in the mental laboratory are processed under controlled conditions to obtain data ation of restorations. (D) Excessive expansion of moisture-contaminated tubing. Casting a dental-gold appliance. (F) The dental interferometer shrinkage of dental amalgam within 24 hours after mixing.

cooperative program, sponsored by the Army Dental Corps and the Veterans Administration, was established at the National Bureau of Standards in 1949 for the study of the properties of dental materials under unusual conditions. Staff and equipment were correspondingly increased.

Dental-Amalgam Alloys

The value of the methods of the physical sciences in the study of the properties of dental materials is well illustrated by the results with dental-amalgam alloys. These alloys of silver, tin, copper, zinc, and mercury have been used to fill cavities in teeth for over 100 years. Formerly dentists experienced a number of difficulties in the use of amalgam, not the least of which was the severe pain often felt by the patient shortly after having a tooth filled. Investigations at the Bureau on such properties as dimensional stability and corrosion resistance of amalgam restorations have done much to eliminate many of these difficulties and have established amalgam as one of dentistry's finest restorative substances. Today more dental restorations are made with amalgam than with all other materials combined.

The Bureau has intensively investigated the fundamental reactions that occur during the hardening of the amalgam and has determined the effects of various alloy-mercury ratios and methods of condensation and finishing. In the course of this work it was demonstrated that postoperative pain with amalgam restorations is caused by moisture contamination. It was found that a small amount of water incorporated in the amalgam during mixing or placing of the filling reacts with the zinc in the alloy to produce hydrogen. This entrapped hydrogen creates pressures that expand the alloy against the underlying tooth structures. As a result of the Bureau's discovery, techniques were developed that now make it possible to eliminate this difficulty entirely.

The possibility of mercury poisoning, at one time considered a serious drawback to the use of amalgam in dentistry, was also investigated. The results show that poisoning from this source is extremely unlikely, as very little mercury can be released by the amalgam under the conditions that prevail in the human mouth. Another study dealt with the possibility of tissue irritation caused by galvanic action when amalgam is placed in the mouth along with more noble metals. Current work on amalgam at the Bureau concerns the metallurgical relations that occur during amalgamation and hardening of the alloy. The Bureau's development of a method for investigating the microstructure of amalgam restorations at room temperature offers a new approach to studies hitherto considered difficult.

Gold Alloys

The casting of gold alloys to the extremely small tolerances required for inlays, crowns, and bridgework has been one of the greatest difficulties experienced by dentists in the use of these materials. Prior to the investigations of the Bureau to determine basic principles involved in precision casting, accurate casting of dental restorations was virtually impossible. The Bureau's determination of the dimensional changes that occur during the casting of gold alloys, together with similar investigations of the dimensional changes of waxes used for making patterns and of gypsum materials for molds, for the first time made it possible for dentists to make precision castings of gold appliances. As a result of this work, the casting technique is now so well defined that it has been adopted by many industries for the manufacture of small objects that must be cast to precise dimensions. The methods developed at the Bureau for the chemical analysis of dental gold alloys have also found widespread acceptance throughout the dental industry, and the data obtained through the use of these methods are being used extensively to develop new and better alloys.

Silicate Cements

The widespread use of silicate cements for filling anterior teeth and the many clinical difficulties involved in their use have led to an intensive investigation of these materials at the Bureau. Silicate cements were first introduced to dentistry in 1878, but

it was not until 25 years later that a product reasonably satisfactory for dental use was produced. In silicates dentists at first believed they had the ideal restorative substance; a durable material resembling tooth enamel in appearance, which could be inserted in the cavity in a plastic state and which would then harden sufficiently to resist attrition in the mouth. In practice, however, these cements soon began to discolor, dissolve, and even worse, to cause the death of the tooth pulp. The primary cause for this failure in use was the lack of information on the fundamental chemical and physical behavior of the cements. Their chemical composition was unknown, and the basic principles involved in mixing the cements were so poorly defined that when a group of practicing dentists was asked to cooperate in determining the amount of powder that could be incorporated in a given quantity of liquid, the values reported ranged from 0.70 gram to 1.69 grams for the same cement. Data on factors that adversely affect the solubility and setting time, crushing strength, hardness, and dimensional stability were either nonexistent or so conflicting as to be of little value. Much of this confusion resulted from the absence of standardized testing procedures. Lack of such fundamental information explains in part why some silicate-cement restorations had to be replaced after 6 months while others gave service for as long as 15 years.

To provide basic data, the National Bureau of Standards began an investigation of silicate cements, with primary emphasis on composition, the chemical reactions involved in hardening, and the factors that influence these reactions. The first complete chemical analysis of all types of silicate cements was made, and methods were developed for determining the factors that influence the solubility, crushing strength, hardness, opacity, acidity, and purity of the cements. As a result of this work, the solubility of silicate cements has been decreased by as much as 50 percent, while their strength has been increased by a similar factor. Impurities such as arsenic, which may irritate the tooth pulp or even cause its death, have been reduced to harmless amounts or eliminated entirely. Techniques have been developed, on the basis of these investigations, which enable the dentist to apply silicate cement with greater assurance that the restoration will be satisfactory and that the underlying tooth structures will not be adversely affected through their use.

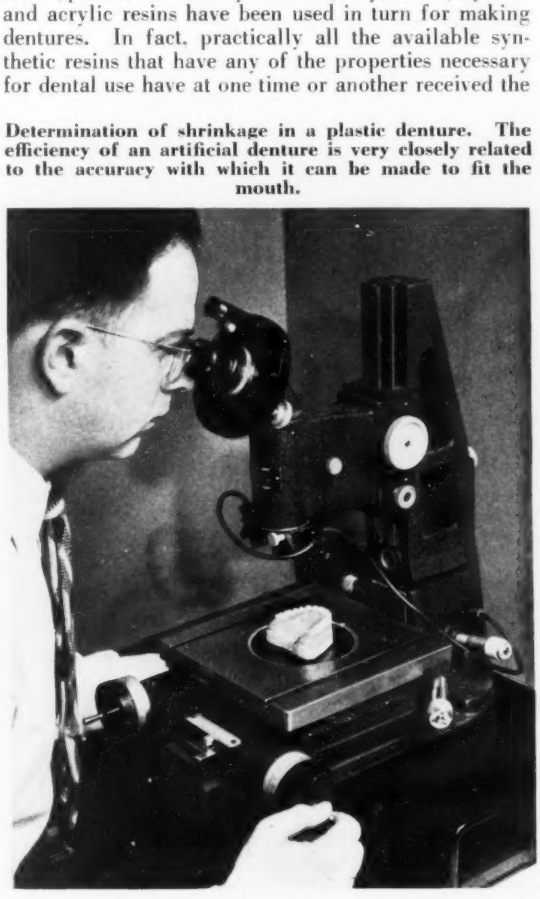
For many years the zinc phosphate cements, like the silicates, proved disappointing in practice. Because of lack of data on their fundamental properties and lack of uniformity in their composition, it was not easy to locate their defects. It was not uncommon at one time to find that some cements were soluble to the extent of 14 percent, whereas the solubilities of others might be as low as 0.14 percent.

Investigations at the Bureau were instrumental in reducing materially the solubility and disintegration of these materials in the oral fluids and brought about an increase in their strength, hardness, and ease of manipulation. Adequate testing procedures for evaluating the properties of the cements were also developed, resulting in a much greater uniformity in the products now offered to dentists.

Denture Resins

Synthetic resins are used for the construction of complete and partial dentures, inlays, crowns, and artificial teeth. Recently they have been employed as direct filling materials. During the past 20 years cellulose resins, phenol formaldehyde resins, vinyl resins, styrene and acrylic resins have been used in turn for making dentures. In fact, practically all the available synthetic resins that have any of the properties necessary for dental use have at one time or another received the attention of dentists and dental manufacturers. Probably no other group of materials has caused the dentist so much difficulty.

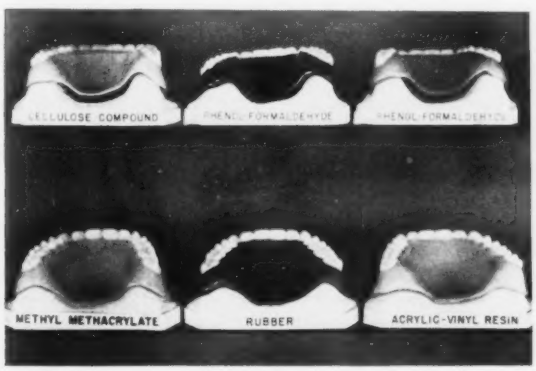
Determination of shrinkage in a plastic denture. The efficiency of an artificial denture is very closely related to the accuracy with which it can be made to fit the mouth.



Most of the resin dentures failed because of a lack of sufficient dimensional stability and strength to withstand the forces of mastication. Since the efficiency of dentures—at best less than 50 percent that of natural dentition—is directly related to the accuracy with which they can be made to fit the hard and soft tissues of the mouth, their dimensional stability is particularly important.

Investigations at the Bureau showed that the cellulose resins change shape radically in service and are partially soluble in the oral fluids. The phenol for-

naldehyde resins were found to be brittle and dimensionally unstable and to change color with age. Moreover, the tendency of these resins to polymerize prematurely at room temperature and the lack of any index for determining the extent of such polymerization made it virtually impossible to develop a standardized technique for curing them. The vinyl resins were also found unsatisfactory, primarily because of strain introduced into the denture during molding and because of the inability of the manufacturers to produce a uniform product. Experiments on polymer distribution in samples of the material revealed variations as great as 100 percent for some of the high polymers. In general, the data showed that acrylic resins and some copolymers of these resins with vinyl resins are the best materials available to the dental profession for making dentures. Nevertheless, difficulties are often encountered with these products if the fundamental principles governing the behavior of the resins are not understood.



Artificial dentures made of some of the materials investigated at the Bureau. Denture materials must cure to an exact fit and must maintain their dimensions unchanged for years. The two most satisfactory materials are methyl methacrylate and the acrylic-vinyl resin.

The Bureau's work on acrylic resins has included the development of both methods and equipment for determining their basic properties and the factors that affect these properties during polymerization and molding. The effect of small amounts of impurities on rate and completeness of polymerization and the influence of temperature, pressure, duration of heating, and mold surfaces [1] on the type of polymer formed have been studied. Methods have also been developed for fractionally precipitating polymers and determining their average molecular weight, for determining small amounts of residual monomer in cured samples of resin, and for correlating the polymerization rate with amount and type of catalyst and inhibitor used. The results explain many of the difficulties encountered in denture construction, such as continued shrinkage in service, fracture, discoloration, crazing, porosity, and premature polymerization of the resins. Other investigations are now in progress on a new group of acrylic resins that polymerize at relatively low temperatures and that have been advocated for use as direct resinous filling materials.

[1] For further technical details, see Surface strain in plastic dentures, NBS Technical News Bulletin **31**, 65 (1947).

Structure of Enamel and Dentin

In order to develop satisfactory methods for preventing tooth decay, there must be some adequate explanation of the processes that occur in the decalcification of teeth. Great differences exist in the resistance of different teeth to decalcification, and these differences are thought to be associated in some way with the manner in which the hard, calcified tooth structures are deposited. However, as yet no satisfactory correlation between tooth structure and resistance to decay has been determined. In an effort to learn more about the problem, the Bureau, in cooperation with the American Dental Association, is investigating the structure of teeth. This program has included work on determination of the hardness of enamel and dentin and studies of the abrasion and decalcification of tooth structures due to the chemical and mechanical action of some toothpaste ingredients. In the course of an investigation of the possibility of remineralization of teeth through the use of fluorides and calcium salts, some of the first electron-microscope studies of the structure of enamel were made. Additional work is now being undertaken using the methods of chemical analysis, X-ray and electron diffraction, and electron microscopy. The present program includes an investigation of the chemistry of the basic calcium phosphates, the major inorganic constituents of teeth. The effect of minute traces of elements on the precipitation and structural characteristics of these basic phosphates is being studied. It is hoped that additional information will be obtained on the chemical and physical nature of teeth that will make it possible to explain the mechanism of decalcification and decay.

Testing by the National Bureau of Standards

This Bureau receives many inquiries regarding the scope of its testing program, the type of tests it makes, and the fees it charges for this service. A new circular, *Testing by the National Bureau of Standards*, describes the Bureau's test policy, presents general information on testing, and lists fees for the test work that is done.

The Bureau's testing and calibration activities stem from its custody of the Nation's basic physical standards. Accuracy and uniformity in measurements throughtout the United States depend on these standards, and Congress has therefore authorized the Bureau to engage in testing work for the Nation in those cases where sufficient accuracy cannot be obtained elsewhere. Fees listed include those for tests on electrical standards and instruments; standards of length, mass, and time; pyrometers; fuels; radioactive standards; and optical instruments.

Circular C483, 93 pages, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 25 cents a copy.

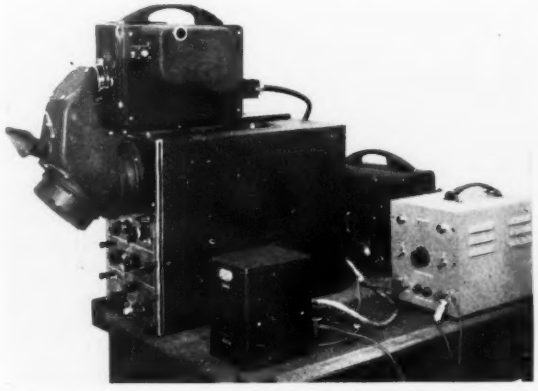
Wide-Band Electrocardiography

Electrocardiographic recorders are under study at this Bureau. The project, headed by S. R. Gilford of the Bureau's electronic instrumentation laboratory, has been directed primarily at the bandwidth and response requirements of such instruments. It involves a series of laboratory tests supplemented by the clinical evaluation of wide-band electrocardiograms by cardiologists. The program is designed to reveal the performance characteristics of commercial electrocardiographs and to determine the features needed in an instrument to produce accurate electrocardiograms for use in the diagnosis of heart disease.

Presently available electrocardiographs differ greatly in speed of response. Faithful recording requires an instrument with a high enough response speed to follow the finest variation of the impressed cardiac signal. Recorder bandwidth is difficult to specify, since the upper frequency limit for cardiac potentials is not definitely known. In the case of mechanical recorders, high frequency performance is limited by the power requirements and inertia of practical writing systems. One of the purposes of the Bureau study is to determine whether presently used electrocardiographic recorders give faithful record of cardiac activity, and what frequency characteristic is needed to provide all the diagnostically important information.

A series of recordings have been made using an instrument of adequate bandwidth to give a substantially undistorted record of cardiac potential variations at the standard clinical lead positions. These records have been compared for differences in form and clinical interpretation with records obtained simultaneously from commercial electrocardiographs. Harmonic analyses were made on certain records to establish a reference for comparisons of the effect of bandwidth on fidelity of recording.

The laboratory equipment used in this program centers around a special electrocardiographic recorder capable of giving undistorted records of cardiac potentials and a reproducer unit for converting any of these records back into electrical form. The reproduced records can be applied to a harmonic analyzer or to selected filter circuits. The special electrocardiographic recorder consists of the following equipment: A differential two-stage voltage amplifier, a cathode-ray oscillograph, and an oscillograph camera to make a moving-film record of the screen image. The upper frequency limit of this recording system is 1,000 cycles per second, an extreme that appears adequate to record the fastest cardiac variations at film speeds near the electrocardiographic standard of 25 millimeters per second. This permits ready comparison with records from commercial instruments under test. The resolution of this wide-band recorder is nearly three times that of ordinary commercial models. High resolution is important in realizing the benefits of high response speed.



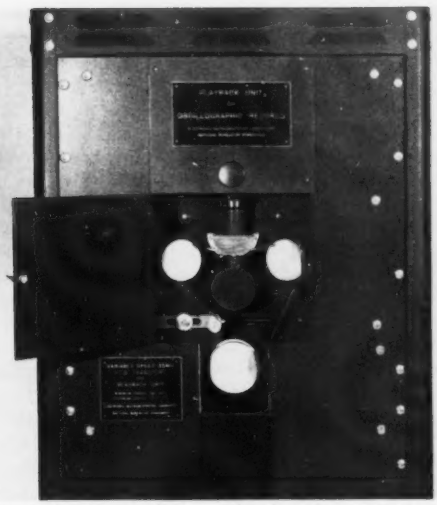
The Bureau's experimental wide-band electrocardiographic recorder provides an undistorted record of heart activity. The recording system consists of a differential two-stage amplifier, an oscilloscope with a blue-image phosphor screen, and an oscillograph camera that makes a moving-film record of the screen image.

The reproducer unit employs an electron-optical system to convert an oscillographic record into an equivalent electrical signal. The film transport system can play back the film record at any speed up to 50 times the original recording speed. The reproducer unit permits the indirect study of cardiac potentials without making additional clinical measurements. This has the important advantage for some phases of the work of providing standard conditions free from the moment-to-moment variations present with actual patients.

The wide-band recorder was set up at the Cardiovascular Research Unit of the Mt. Alto Veterans Hospital whose staff cooperated fully in this study by making all clinical records and providing all medical interpretation of the results. A total of 160 electrocardiograms representative of many types of normal and abnormal cardiac behavior were obtained under clinical conditions.

The comparative study of these simultaneous records showed that although easily discernible distortion exists in the records, in no case did it result in errors in clinical interpretation. Present clinical practice does not require precision recording; the additional detail is not subject to any agreed upon interpretation, nor is more accurate measurement of the known significant portions of an electrocardiogram needed for general clinical work. It is nevertheless important to understand the types of errors that can occur and the circumstances under which they are likely to appear.

The greatest departure from accurate recording occurs with instruments of the direct-writing type when the impressed cardiac signal displays rapid activity. In most cases this can be traced to inadequate high-frequency response. The string galvanometers generally



The reproducer unit designed by the Bureau for its study of electrocardiographic recorders converts a film-type electrocardiogram into an electrical signal that closely resembles the original cardiac signal.

show this type of cardiac activity better, although poor resolution and slow writing rate sometimes make interpretation difficult.

For some types of medical research it would be desirable to obtain electrocardiograms of maximum accuracy. This is particularly so in studies leading to the establishment of normal standards. Also, it would be desirable to investigate the additional small detail brought out by the wide-band recorder to see if it has any diagnostic significance. In some kinds of electrocardiographic research a wider bandwidth is a necessity. This is the case with small animals where the electrical activity is considerably more rapid, and might well be the case with infants and young children whose heart rate is higher than in adults.

The harmonic analysis of typical electrocardiograms has shown a predominantly low frequency distribution, but in some cases the spectrum extends well beyond 100 cycles per second. Although the amplitudes of these higher frequency components are low, it is possible that they contribute significantly to the fine detail found in records exhibiting fast activity.

The convenience of the direct-writing instrument justifies its use for clinical purposes, since the distortions it can introduce do not alter the cardiologist's interpretation. Higher fidelity apparatus should be used, however, for medical research in the establishment of standards and wherever the rapid electrical activity is important.

Latin and Youden Squares

Statistical Designs for Greater Precision

Special statistical designs are now demonstrating their usefulness in several research projects at the National Bureau of Standards. Bureau scientists have adopted cross-overs, Latin squares, and Youden squares in the road testing of truck tires, in precise determinations of radioactivity, in rating the adherence of enamel, and in measuring the temperature of chemical cells. Statistically planned experiments offer greater precision and economy in every field of research, and for that reason active work on the design of experiments is being carried on at the Bureau by W. J. Youden of the statistical engineering laboratory.

Accuracy of results is a goal in any scientific investigation, but precision in measurement is prerequisite to accuracy. This is because the accuracy of results cannot be ascertained unless there is agreement in the results of different procedures, and in order to determine whether or not procedures agree it is necessary that the measurements in each be precise. There is here the tacit assumption that it would be very unlikely for two or more different procedures to be affected with the same bias, and therefore agreement among results indicates freedom from bias.

It is well recognized that statistical measures of error are concerned with revealing the precision of a set of data. This limitation on the applicability of statistical techniques is not as severe as, at first, it appears to be. Most scientific investigations are not directly concerned with absolute measurements, and ultimate considerations of accuracy do not arise. Rather, as in the calibration of a secondary against a primary standard, there is a comparison of similar measurements. The existence of a bias in the measurement process may then be of no consequence. If the bias is the same for measurements on both the primary and secondary standards, the difference between the sets of measurements will be unaffected. It is even possible that a better comparison may be obtained with a method known to have bias if the precision of this method is better than that of unbiased methods.

For best precision, the experimental conditions must be held as constant as possible during the whole series of measurements. The error in the average of n measurements is $1/\sqrt{n}$ as large as the error of a single measurement. Four measurements will reduce the error of the average by a half, but 16 measurements are required to reduce it to one-fourth that of a single measurement. This diminishing return is sometimes advanced as an argument against the use of long series of repeated measurements, but a more important reason is found in the increasing difficulty of maintaining contant conditions over the longer periods of time required for lengthy series. If the experimental conditions were to vary, the attempt to improve a comparison by making more measurements would be defeated.

In spite of every precaution it is often impossible experimentally to hold conditions constant for any extended period or to isolate and correct for all the disturbing factors that creep in. The problems that arise in controlling the sources of error are found in a Bureau study involving temperature measurements on cells containing a very pure substance. These cells, developed at the Bureau as a way of setting up a definite temperature, maintain the temperature of the melting point of the substance for at least 24 hours. The temperature of a cell is measured with a resistance thermometer left overnight in the cell to attain thermal equilibrium.

The object of the study was to determine the reproducibility of the temperature when a given cell is used repeatedly and to check the agreement between the temperatures set up by several cells filled with the same substance. The problem has special interest because it was believed that the cells could reproduce temperatures with as good a precision as that attained in calibrating the thermometers.

A separate thermometer must be used for every cell being compared on the same day; if the same thermometer is used, measurements require several days. Thus the use of separate thermometers and the extension of the measurements over a number of days are potential sources of error. Effects from these sources of error can be eliminated from the comparisons through the use of an appropriate arrangement of the work.

The following schedule, known as a cross-over, shows an experimental arrangement for two thermometers and two cells for 4 days. The temperature readings for each cell-thermometer pair have been reduced by a constant and then multiplied by 10^4. The entries opposite readings are, therefore, in ten-thousandths of a degree centigrade.

Day	1		2		3		4	
Cell	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Thermometer	*a*	*b*	*a*	*b*	*b*	*a*	*b*	*a*
Readings	35	27	32	17	39	17	43	13
Day average	31.0		24.5		28.0		28.0	
Pair difference	8.0		15.0		22.0		30.0	

The two cells and the two thermometers were used on all 4 days, and both cells were measured twice with each thermometer. The average values are:

Cell *A*	Cell *B*	Thermometer *a*	Thermometer *b*
37.25	18.50	24.25	31.50

As a result of the above arrangement, should the two measurements made on any particular day be high (or low) for reasons peculiar to that day, it will be noticed that all four of the above averages will reflect this fact but that the differences between the cell (or thermometer) averages will not be affected. In a similar manner should there exist a disagreement between the calibrations of the two thermometers the cell averages will be equally affected, since both cells are read twice with each thermometer. Consequently, any variation that might exist between thermometers will not influence the difference between the averages for the two cells. The variation between thermometers is revealed by the difference of the averages for the thermometers, and because of the symmetry of the experimental arrangement, the difference will not be altered by any constant difference between cells (or days). It is an advantage of this arrangement that it explores the performance of thermometers as well as of cells.

An estimate of the precision of these improved comparisons can be obtained directly from the data. Each particular cell or thermometer will exhibit a small bias in its departure from the behavior of an ideal cell or thermometer. A given cell-thermometer pair, say *Aa*, has in turn its own composite bias. The difference between the two readings taken on the first day is a measure of the difference between these two composite biases, and since it is a difference any effect associated with that day drops out. The second day's pair of readings provides a duplicate determination of this same quantity. The discrepancy between these two differences $(15.0-8.0)$ is ascribable to sources of error still remaining in the experiment. This discrepancy times $1/\sqrt{2}$ is a fair indication of the difference that might be expected between two readings if it were possible to make them on the same cell on the same day using the same thermometer. This is the appropriate error for appraising the observed difference between cells (or thermometers) since the symmetrical arrangement neutralizes the effect of thermometer and day characteristics insofar as they apply to comparisons between cells.

The third and fourth days contribute another estimate of this error, and a more reliable estimate of the error may be obtained by combining the separate estimates with other estimates similarly obtained. The presence of day-to-day errors is revealed by taking the averages for the two measurements made on each day. Since identical combinations were used on the first 2 days, the difference between the 2-day averages must arise from some circumstances associated with the days. The averages for the third and fourth days also contribute to the detection of day-to-day effects.

An alternative experimental arrangement, especially useful when several cells are involved, is called the Latin square.

Thermometer	Cell			
	A	*B*	*C*	*D*
a	1	2	3	4
b	2	1	4	3
c	3	4	1	2
d	4	3	2	1

In this example four cells and four thermometers are used, and four measurements are made on each of 4 days. The numbers in the diagram show the cell-thermometer combinations to be used on days 1, 2, 3, and 4. If the data were inserted in the diagram, the column and row averages would give values for cells and thermometers. Cell averages are, for comparisons between cells, as reliable as those that would be obtained with identical thermometers under conditions maintained as constant for 4 days as they can be held for 1 day. This is also true for comparisons between thermometer averages. Differences between days are shown by the averages for the values associated with each number in the diagram. Estimates of the precision of the comparisons may be readily obtained by the use of formulas given in statistical texts dealing with the analysis of variance.

The preceding two arrangements call for the same number of thermometers as cells. The following schedule, a form of Youden square, shows how seven cells may be intercompared using only three thermometers and making just three measurements on each of 7 days.

Thermometer	Cell						
	A	*B*	*C*	*D*	*E*	*F*	*G*
a	1	2	3	4	5	6	7
b	7	1	2	3	4	5	6
c	5	6	7	1	2	3	4

How this arrangement balances out the thermometer and day effects is shown by selecting a given cell, say *A*, and noticing that for each day on which this cell is used it may be compared with the averages of two of the other six cells. The letter subscripts show the thermometer used with each cell.

$$\text{Day 1} \quad 2A_a-(B_b+D_c)=A_1$$

$$\text{Day 5} \quad 2A_c-(E_a+F_b)=A_5$$

$$\text{Day 7} \quad 2A_b-(C_c+G_a)=A_7$$

$$\text{Identity} \quad A-A \qquad =0$$

$$\text{Sum} \quad 7A-(\text{all cells})=A_1+A_5+A_7$$

The differences A_1, A_5, and A_7 are free from day effects, and $A_1+A_5+A_7$ is also free from thermometer effects since the bias, if any, of thermometer *a* cancels from $2A_a-E_a-G_a$ and similarly for thermometers *b* and *c*. The identity $A-A=0$ is included in the sum so that, on dividing the sum by 7, A may be expressed in terms of the average for all cells.

$$A=\text{average of all}+\frac{1}{7}(A_1+A_5+A_7)$$

$$B=\text{average of all}+\frac{1}{7}(B_1+B_2+B_6)$$

$$\cdot \qquad \cdot \qquad \cdot \qquad \cdot \qquad \cdot$$

$$G=\text{average of all}+\frac{1}{7}(G_4+G_6+G_7)$$

Thus differences between the cell averages are known in terms of quantities such as $(A_1+A_5+A_7)$, which are free from day effects and in which thermometer effects are also neutralized.

The comparisons of thermometers are obtained directly from the average for each thermometer, since all three thermometers were used once with each cell and also used every day.

These arrangements require that each cell be found with every other cell, on one or another day, an equal number of times. With four thermometers and seven cells each cell is associated twice with the other six cells. Some other possible combinations are 4 thermometers and 13 cells, 5 and 11, 6 and 16, 7 and 15, 5 and 21.

The experimental arrangements given here show that a thought-out scheme for pairing thermometers and cells, combined with a well-planned time schedule for making the measurements, improves the precision of the comparisons that the investigator has in mind. These comparisons are required in order to ascertain the reproducibility of the temperature set by a given cell and to determine how various cells agree among themselves. The arrangements do not introduce any complications in the experimental work or call for any changes in technique. Indeed, insofar as these arrangements obviate the necessity for reproducing and maintaining the environmental conditions, the burden upon the investigator is lightened as the precision of the measurements improves.

Stack Venting of Plumbing Fixtures

Individuals and groups responsible for the preparation of plumbing codes will find much pertinent information in a booklet recently published by the National Bureau of Standards entitled *Stack Venting of Plumbing Fixtures*. This publication answers a number of questions regarding the adequacy of stack venting plumbing fixtures for one- and two-story dwellings. The use of stack-vented fixtures effects a considerable reduction in the cost of plumbing installations in a dwelling, but may only be used in certain restricted circumstances. In order to make all flow phenomena visible, the Bureau used pipes, traps, connections, and vents made of transparent plastics. The report describes test procedures and discusses and interprets results.

Building Materials and Structures Report BMS118, by John L. French, 21 pages, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for 15 cents a copy.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **44,** number 4, April 1950. (RP2082 to RP2090, incl.)

Technical News Bulletin, volume **34,** number 4, April 1950. 10 cents.

CRPL–D68. Basic Radio Propagation Predictions for July 1950. Three months in advance. Issued April 1950. 10 cents.

Research Papers

RP2072. Introduction of measured liquid samples into the mass spectrometer. C. Edward Wise, Robert M. Reese, Vernon H. Dibler, and Fred L. Mohler. 10 cents.

RP2073. Heats of polymerization. A summary of published values and their relation to structure. Donald E. Roberts. 10 cents.

RP2074. Stress corrosion of wrought magnesium base alloys. Hugh L. Logan and Harold Hessing. 10 cents.

RP2075. Preliminary list of levels and *g*-values for TaII. C. C. Kiess, H. R. Harrison, and W. J. Hitchcock. 5 cents.

RP2076. Electrode function (pH response), hygroscopicity, and chemical durability of Na_2O-CaO-SiO_2 glasses. Donald Hubbard, Given W. Cleek, and Gerald F. Rynders. 10 cents.

RP2077. Soil corrosion studies, 1946 and 1948: Copper alloys, lead, and zinc. Irving A. Denison and Melvin Romanoff. 20 cents.

RP2078. Mass spectra of nonanes. Fred L. Mohler, Laura Williamson, C. Edward Wise, Edmund J. Wells, Helen M. Dean, and Evelyn G. Bloom. 10 cents.

RP2079. Syntheses and properties of two olefins, six paraffins, and their intermediates. Thomas W. Mears, Abraham Fookson, Philip Pomerantz, Edwin H. Rich, Cecil S. Dussinger, and Frank L. Howard. 10 cents.

RP2080. Effect of deuteration, oxidation, and hydrogen-bonding on the infrared spectrum of cellulose. John W. Rowen and Earle K. Plyler. 10 cents.

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Applied Mathematics Series

AMS8. Table of powers of complex numbers. Herbert E. Salzer. 25 cents.

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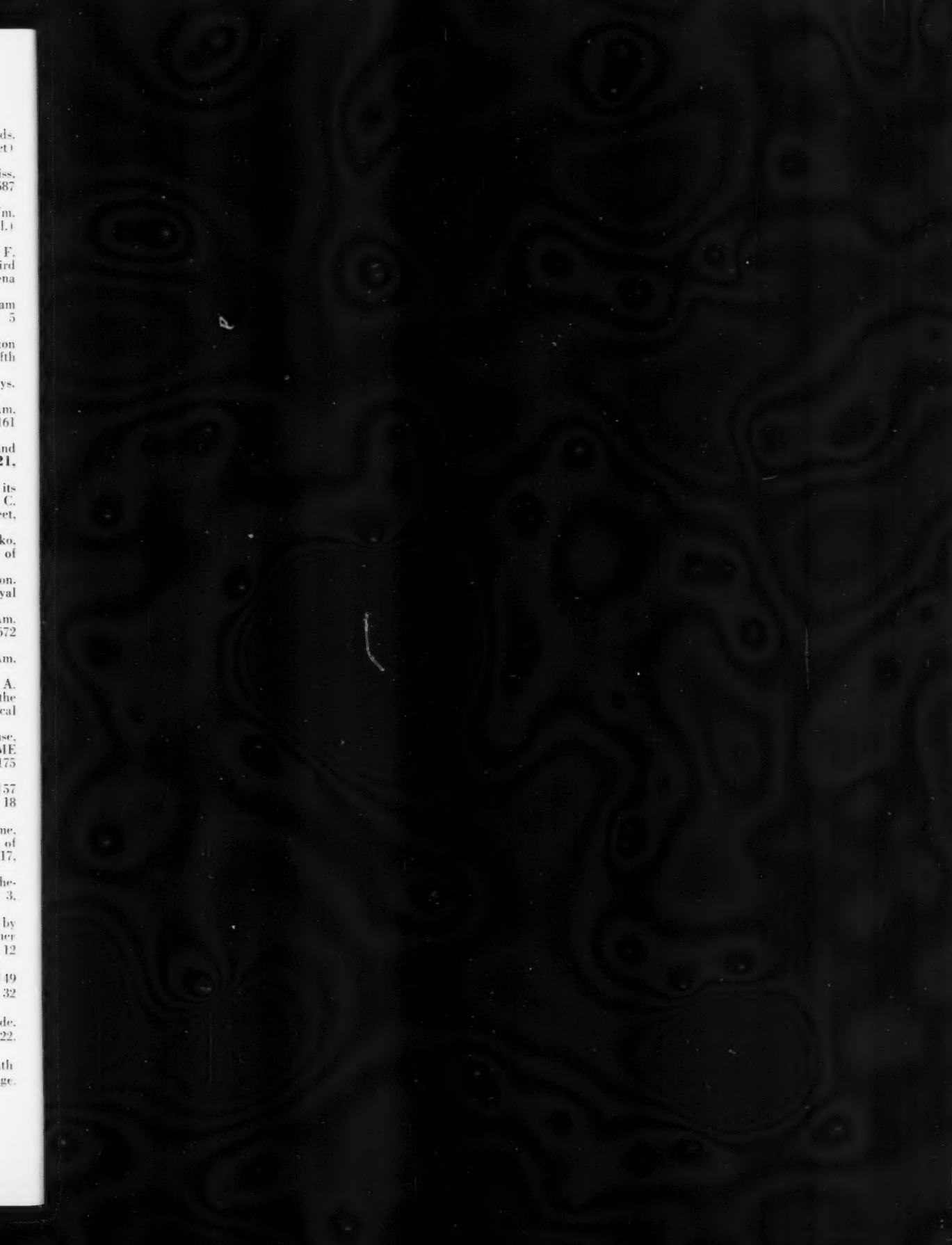
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